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NATIONAL DEFENSE RESEARCH COMMITTEE

of

OFFICE OF SCIENTIFIC RESEARCH AND DEVELOPMENT

WAR METALLURGY DIVISION

Progress Report

on

PLASTIC FLOW OF ALUMINUM AIRCRAFT SHEET UNDER COMBINED LOADS-II
(NA-150)

by

JOHN R. LOW, JR. AND T. A. PRATER
PENNSYLVANIA STATE COLLEGE

OSRD No. 3539

Serial No. M-249

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April 19, 1944

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April 19, 1944

To: Dr. James B. Conant, Chairman
National Defense Research Committee of the
Office of Scientific Research and Development

From: War Metallurgy Division (Div. 18), NDRC

Subject: Progress Report on "Plastic Flow of Aluminum Aircraft Sheet Under Combined Loads-II" (NA-150)

The attached progress report submitted by John R. Low, Jr., Technical Representative on NDRC Research Project NRC-52, has been approved by representatives of the War Metallurgy Committee in charge of the work.

This report describes the results of a study of the effect of specimen size (length and width) on the limiting elongation values in tension and the distribution of these values as a function of gage length for 0.040" Alclad 24-SO sheet.

I recommend acceptance as a satisfactory progress report under Contract OEMsr-864 with Pennsylvania State College.

Respectfully submitted,

Clyde Williams

Clyde Williams, Chief
War Metallurgy Division, NDRC

Enclosure

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PREFACE

This report is pertinent to the problems designated by the Office of the Coordinator of Research and Development, Navy Department, as NA-150, and to the project designated by the War Metallurgy Committee as NDRC Research Project NRC-52.

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PROGRESS REPORT

N.D.R.C. Research Project NRC-52 Contract No. OEMsr 364

PLASTIC FLOW OF ALUMINUM AIRCRAFT SHEET UNDER COMBINED LOADS-II

November 1, 1943 to February 1, 1944

From: Department of Metallurgy, The Pennsylvania State College

Report prepared by: John R. Low, Jr.
T. A. Prater

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FOURTH QUARTERLY

PROGRESS REPORT

N.D.R.C. Research Project NRC-52 Contract No. OEMsr 864

PLASTIC FLOW OF ALUMINUM AIRCRAFT

SHEET UNDER COMBINED LOADS-II

November 1, 1943 to February 1, 1944

From: Department of Metallurgy, The Pennsylvania State College

Report prepared by: John R. Low, Jr.
T. A. Prater

ABSTRACT

This report describes the results of a study of the effect of specimen size (length and width) on the limiting elongation values in tension and their distribution as a function of gage length for 0.040" Alclad 24-SO sheet. On the basis of these results it is proposed to confine future tests on other grades and tempers to two modified tension specimens and the standard A.S.T.M. sheet specimen. One of the modified tension specimens will be of sufficient length (12") so that the uniform as well as the local elongation may be determined. The other will be a wide specimen with curved edges so designed as to limit lateral contraction to a minimum during stretching in the tension direction.

FOURTH QUARTERLY

PROGRESS REPORT

N.D.R.C. Research Project NRC-52 Contract No. OEMsr 864

PLASTIC FLOW OF ALUMINUM AIRCRAFT SHEET UNDER COMBINED LOADS-II

November 1, 1943 to February 1, 1944

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I. Introduction

The purpose of the present investigation is to determine the plastic behavior of aluminum aircraft sheets for various combinations of the principal strains in the plane of the sheet. As a part of this testing program it is necessary to know the effect of specimen size and shape on the amount of flow which precedes fracture in the simple tension test. The results of such a study will, for example, indicate to what extent ductility values obtained from a standard sheet tensile specimen are representative of those to be expected in stretching sheets of larger dimensions. Further, the present investigation provides information on the manner in which the elongation vs. gage length curves are changed when the deformation is confined to short gage lengths under conditions of severe lateral restraint.

II. Experimental Procedure

Specimen Preparation:

The specimens used in the investigation varied in width from ½" to 10" and in gage length from 1" to 12", giving length/width ratios ranging from 0.10 to 17. The edges of the specimen were milled parallel and any burrs resulting from this step were removed with a sharp scraper. No filing or polishing of the specimen edges was done. A 100 line per inch grid was then printed on each specimen employing the "photo-grid" technique. The grid obtained by this process was accurate within ±4.0% over a gage length of 0.01"; ±1.0% over a 0.05" gage; and ±0.2% over a 1.0" gage.

Gripping and Alignment:

In some of the tests simple rectangular specimens with no reduced section were employed. Although four different methods of gripping the specimen were tried, it was found that in most instances specimens of this design fractured in or very close to the front edge of the grip. Later specimens were milled with a fillet of 1¼" radius and a shoulder ¼" wider than the gage section (Fig. 1). This design proved satisfactory for specimens not exceeding 5" in width, but for the wider specimens it was necessary to increase the fillet radius to 3" and the shoulder width to 1" greater than the gage section to ensure a fracture within the section of reduced width. All data reported are taken from

specimens with a reduced section except where otherwise designated.

The specimens ½" wide were gripped in Templin sheet grips which were held in modified Robertson shackles. Each was carefully aligned by placing 1" gage length Tuckerman optical extensometers on either side of the specimen and shifting the grips until the elongation on each side was the same for any given change in load. The wider specimens were gripped between files and aligned by keeping the specimen edges perpendicular to the front edges of the two sets of gripping files. Before testing the distance between the two sets of jaws was measured at the two edges of the specimen to further check the alignment.

Material:

All of the results herein described apply to 0.040" Alclad 24S-O sheet tested in the rolling direction.

III. Effect of Specimen Size

Photo-elastic studies(1) show that the portion of a tensile test specimen which is not in simple tension varies with specimen width and radius of fillet. Dorn and Finch(2), in their work on magnesium alloys, have found that, if the radius of the fillet is kept equal to the width of the gage section, the portion of the test specimen not in simple tension extends from the fillet into the reduced section to a distance approximately equal to the specimen width. In the present tests, the portion of the test

specimen in simple tension was taken as that section which had a uniform percentage of lateral contraction. The extent of this section was determined after the completion of the test by measuring the lateral contraction over a 0.2" gage length along the center line of the specimen at convenient intervals. The percent contraction at each point was then calculated from the relationship: $\% \text{ contr.} = \frac{W_o - W_f}{W_o} \times 100$ where $W_o = 0.2"$, and W_f = distance across 20 grid squares after test. These values were then plotted against their positions along the gage section (Fig. 1) and the length with uniform lateral contraction determined graphically. The percent uniform lateral contraction appears to be independent of specimen width and varies between 5.0% and 6.5%. (Table I) It appears that the only effect of specimen width on lateral contraction is that the narrower specimens show some lateral necking in the immediate vicinity of fracture thus producing greater elongations (and contractions) over short gage lengths near the fracture. Curve "b" in Fig. 1 has been drawn for a specimen that shows a uniform lateral contraction lower than that found to be representative of a condition of simple tension. This behavior was also exhibited by a specimen 10" wide with a 1" gage length. It appears that these specimens are of such shape and dimensions that equal lateral stresses are set up over an appreciable gage length resulting in a section of uniform lateral contraction although none of the specimen is in simple tension.

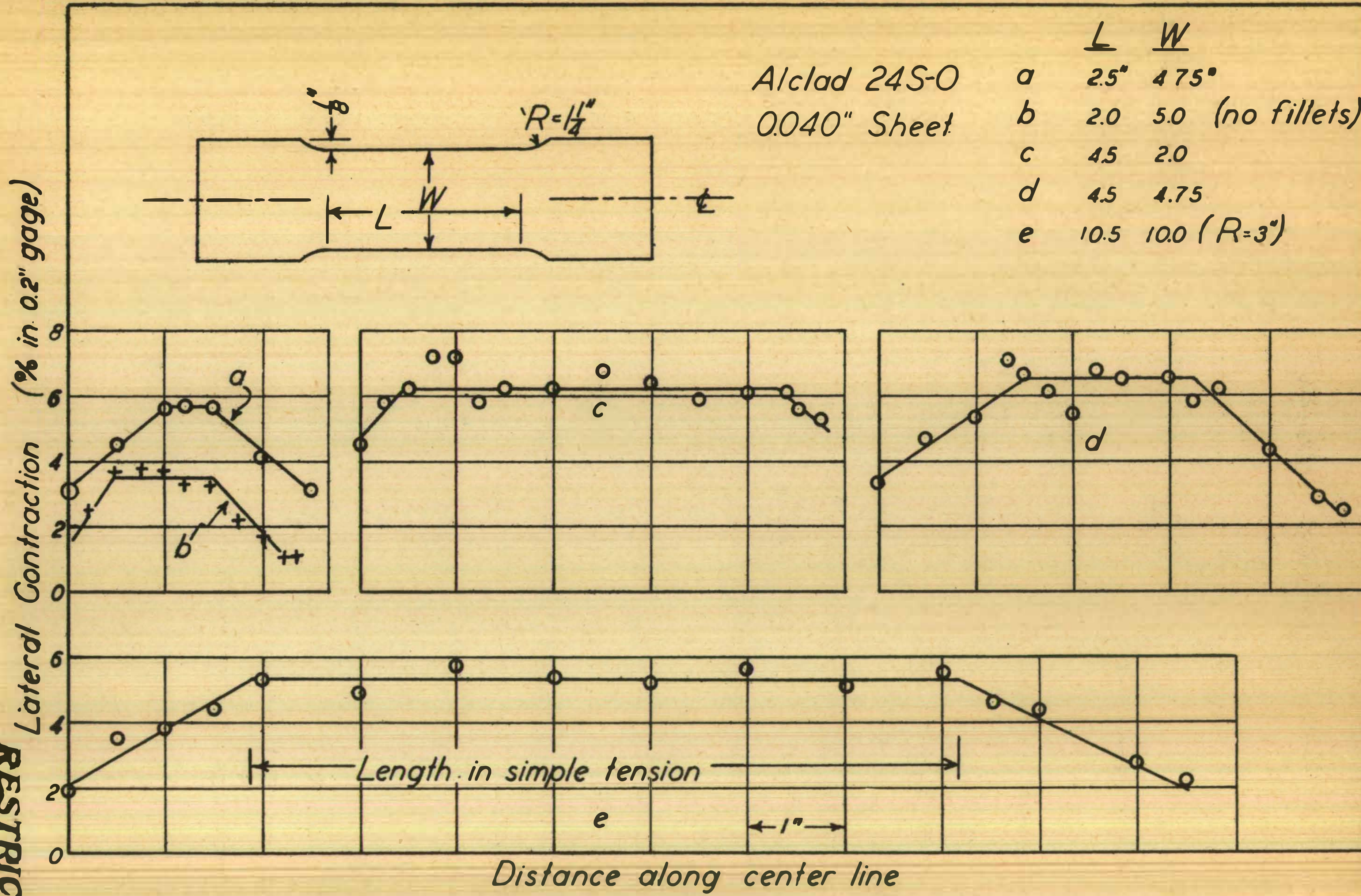


Fig. 1 *Method of determining length in simple tension from lateral contraction measurements*

TABLE I.

Effect of Specimen Dimensions on Elongation and Lateral Contraction

Specimen Dimensions (inches) L	W	Uniform Lateral Contraction (in/in)	Lateral Contraction at Fracture (in/in)	Elongation for Zero Gage Length (in/in)	Limiting Uniform Elongation (in/in)
2½	½	.059	.101	1.11	.165
4½	½	.059	.076	1.18	.159
12	¾	.050	.106	1.35	.160
4½	2	.062	.064	1.52	.198
2½	4¾	.056	.057	1.21	.195
4½	4¾	.065	.066	1.11	.180
10½	10	.053	.053	1.33	.165

All values refer to region in simple tension.

The percentage of the gage section with uniform lateral contraction, i.e., in simple tension, has been plotted against the ratio: L/W, where L = the length between fillets and W = the gage width, (cf. Fig. 2). It is seen from this plot that for the design specimens used in this investigation the length of the reduced section must be at least one-half as great as its width or there will be no section in simple tension. The fraction in simple tension increased rapidly as L/W is increased until that ratio reaches a value of approximately 2 after which the increase is comparatively slow.

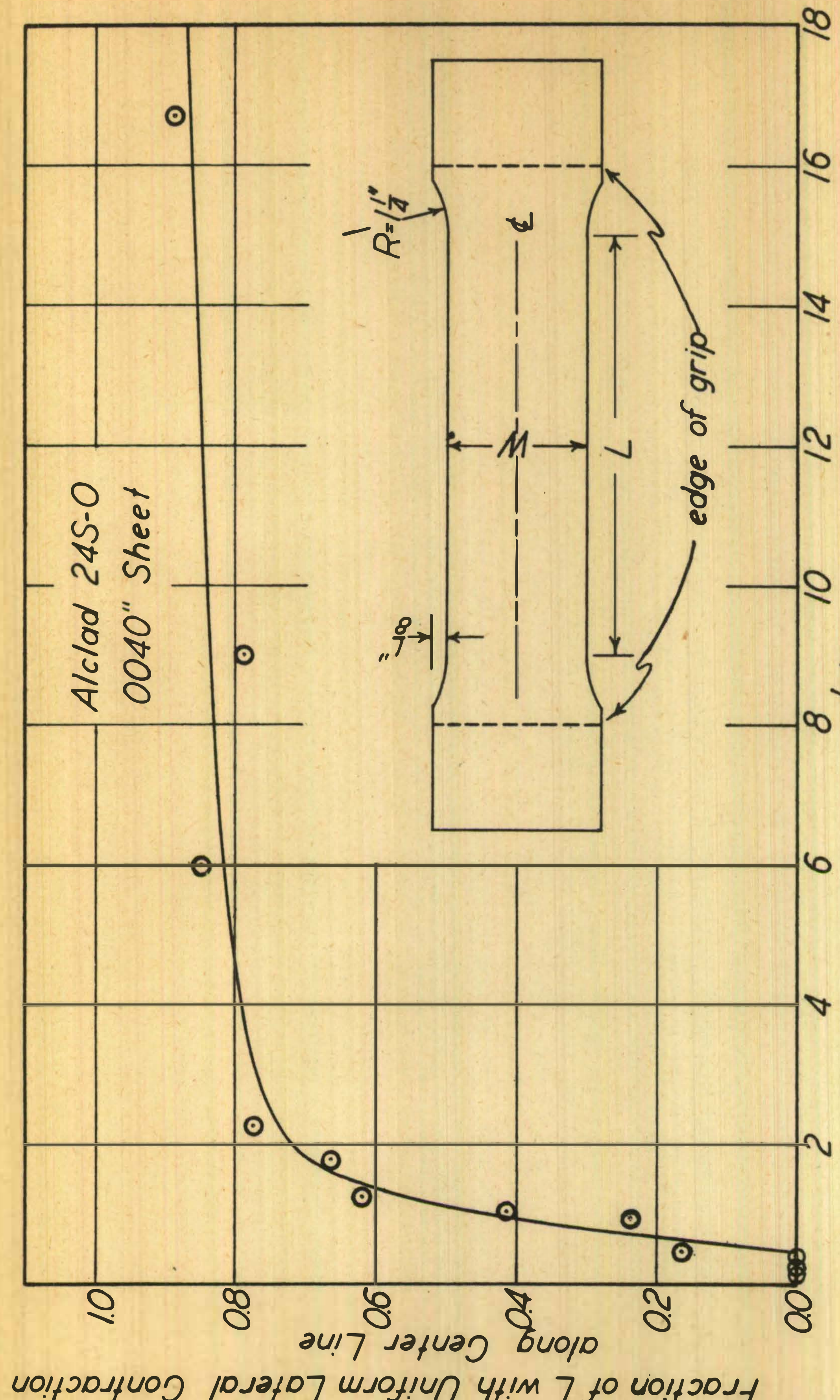
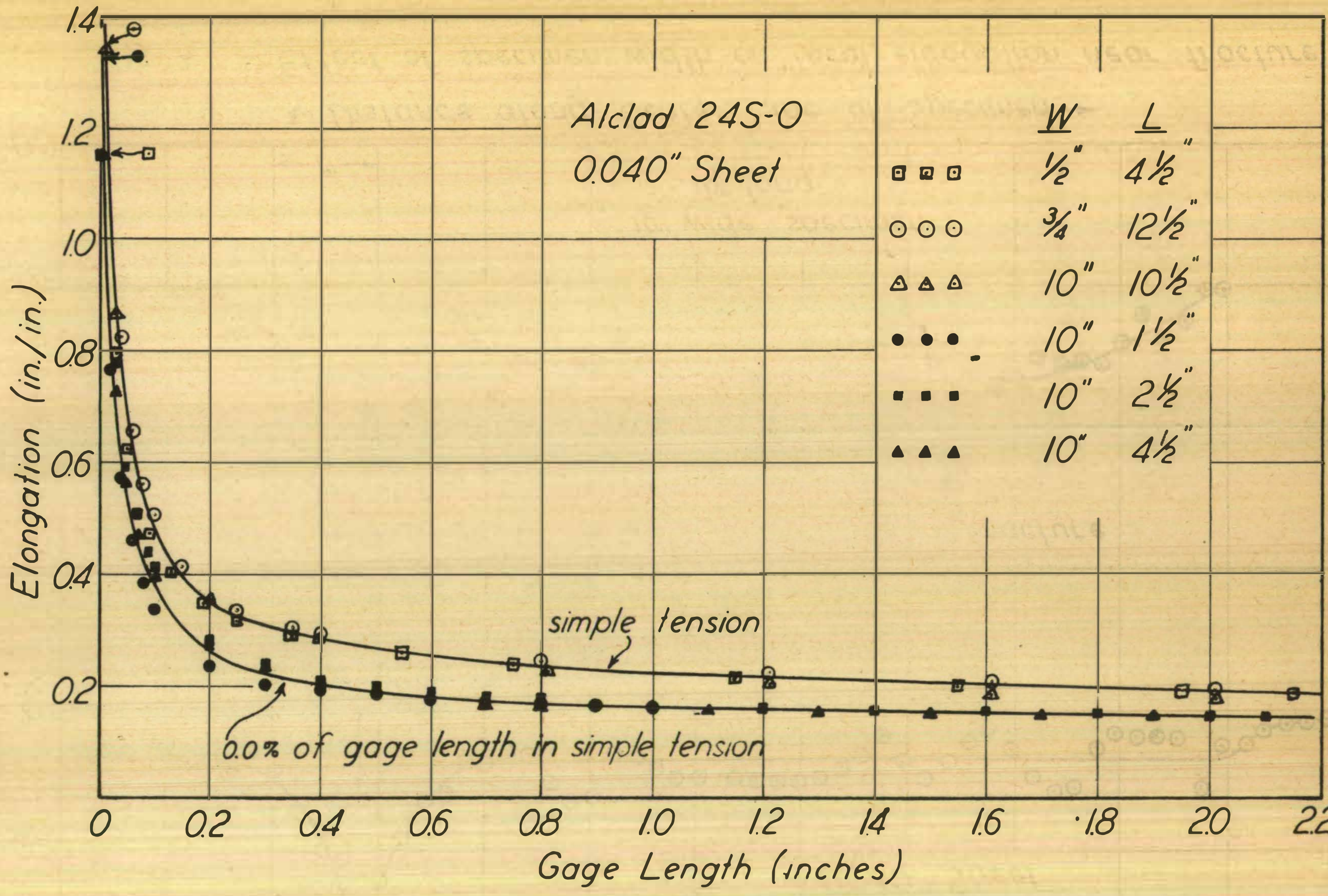


Fig. 2 Effect of specimen dimensions on fraction of reduced area in simple tension

In Figure 3 elongation has been plotted as a function of gage length for six specimens. In three of these the entire length covered by the curves is in simple tension, and in the other three there is no region in which that condition exists. The curves fall into two distinct groups with the specimens in simple tension exhibiting the greater elongation. This effect is most marked for gage lengths under one to one and one-half inches. From these curves it is observed that elongation to fracture is not affected by specimen width provided the specimen length is great enough to permit a state of simple tension. The only exception to this is a slight lowering of the elongation-gage length curve in the region of short gage lengths in the case of wide specimens. This minor variation is due to the lateral necking which occurs in the narrower specimens, but is not observed in those exceeding 2" in width. While the elongation over a zero gage length does not seem to be a function of width, the elongation over comparatively short gage lengths (i.e., .05" to .50") is increased in the narrower specimens because of the greater gage length affected by the neck. As shown in Fig. 4 this region extends for approximately 1½" in the ¾" specimen and for only about ½" in the 10" specimen.



Effect of biaxial stress condition in the plane of the specimen on elongation to fracture

Fig. 3

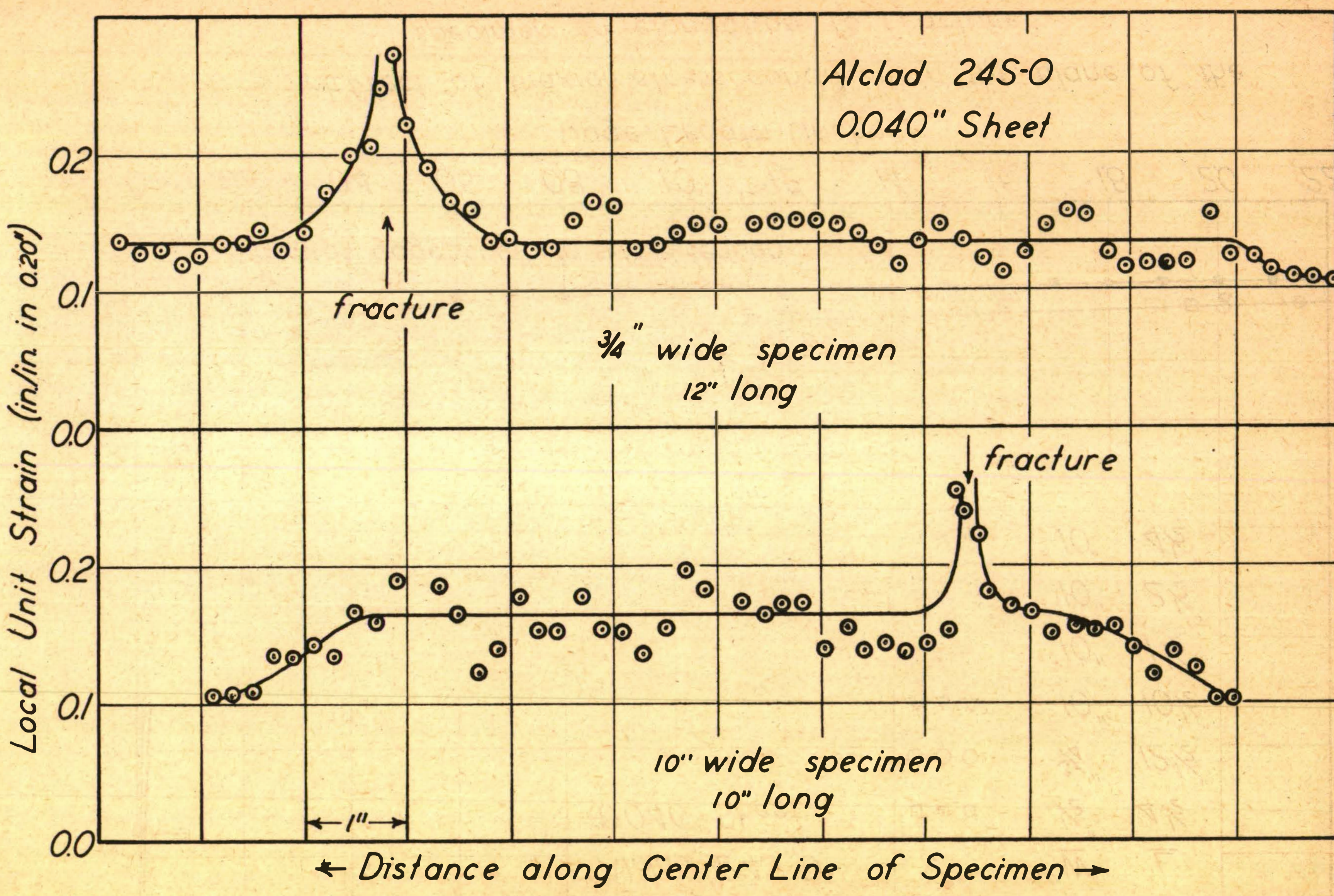


Fig. 4 Effect of specimen width on local elongation near fracture

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IV. Summary

It has been found that lateral contraction measured at intervals along the specimen center line parallel to the direction of loading is a sensitive measure of stress conditions in the plane of the sheet and can be used to determine the actual length in pure tension, that is, the length of the specimen which is not affected by the fillets or grips.

Within the region of simple tension neither the lateral contraction nor the elongation to fracture appear to be affected by increasing the specimen width or length except that for very narrow specimens (less than 2" wide) some lateral necking occurs. As a result the elongation values measured in the immediate vicinity of fracture (i.e., over short gage lengths) are slightly higher than those obtained with wide specimens.

The fraction of the specimen length in simple tension may be plotted as a function of the ratio: length/width. When this is done it is found that for the 0.04" thick sheets being tested and the particular shape used, this fraction begins to decrease rapidly as L/W decreases below 2.0 and becomes zero in the vicinity of L/W = 0.5. As the fraction of the length in simple tension decreases the curve for elongation vs. gage length is shifted to lower elongation values.

The above observations are based on tests on Alclad 24S-0 specimens 0.04" thick and varying in length from one to twelve inches and in width from one-half to ten inches.

V. Plans for Future Work

On the basis of these results it is proposed to standardize on two tests in the future: one, a tension test on a specimen of sufficient length to obtain simple tension conditions over sufficiently long gage lengths to be able to evaluate the uniform elongation (i.e., infinite gage length) as well as the elongation values for shorter gage lengths; the other, a tension test using a wide specimen with curved edges (cf. Third Quarterly Progress Report) so designed as to limit the lateral contraction to a very small value approaching zero.

These two tests together with the elliptical and spherical bulge tests of NRC-51 at The Carnegie Institute of Technology will make it possible to obtain elongation values for a large variety of combinations of the principal strains. Tests are to be made in both the rolling and transverse directions and in sufficient number to indicate the range of scatter which may be expected.

At the present time 0.04" sheets are on hand in the following grades: Alclad 24S-0, 24S-T, and 24SR-T. Other alloys and tempers are to be included in the testing program as soon as sheets can be obtained for testing.

VI. References

1) E. G. Coker and L. N. G. Filon: Photo-elasticity, Cambridge University Press 1931, pp. 560-578.

2) J. E. Dorn and D. M. Finch: Final Report on "Properties and Heat Treatment of Magnesium Alloys: Part I The Effect of Size upon Tensile Properties of Specimens of Magnesium Alloy Sheet" (NA-144).